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RESULTS OF FIELD

MEASUREMENTS

Contract No. [ ]   50X1

15 February 1953.

WASHINGTON - TSS- PRO-4

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INTRODUCTION

The purpose of the field tests was to determine experimentally the attenuation of electromagnetic waves in soil. Theory indicates that the attenuation should be small for the frequency range of 50 to 150 kc. The results of the experiment are in general agreement with the calculations.

Description of Experiment

The site consisted of two ditches 2 feet wide, 6 feet deep and 25 feet long. The trenches were parallel to each other and were separated by a wall 5 feet wide. The soil was a mixture of gravel, clay, and sand.
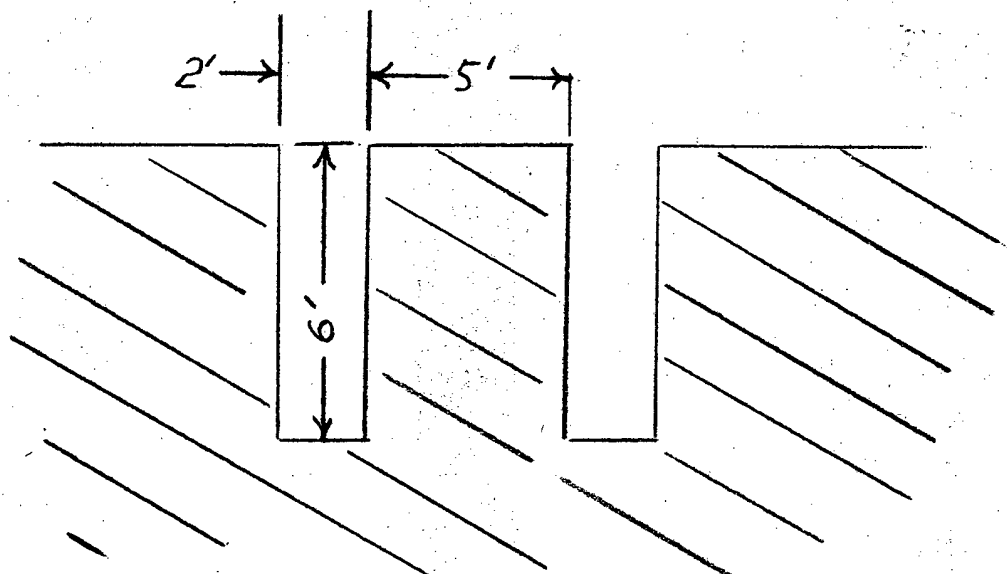

Figure 1. Cross Section of Test Site

The equipment used for the experiment consisted of two identical coils[1], one used as the transmitter and the other as the receiver.

[1] See APPENDIX A for Coil Parameters.
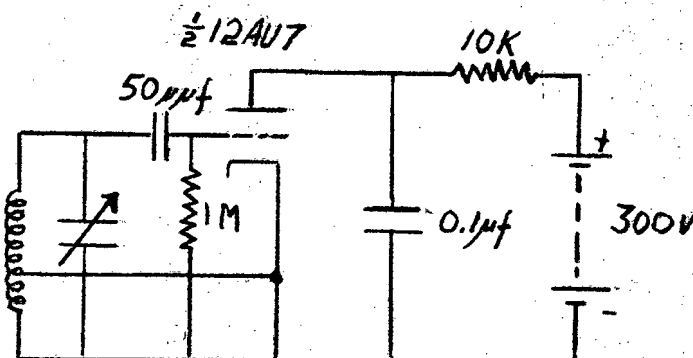
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Figure 2. Transmitter Circuit

The transmitter circuit, shown in Figure 2 consisted of a

Hartley oscillator operating at 90.4 kc. Plate and filament voltages

were supplied by means of batteries.

The receiver, shown in Figure 3 consisted of a tuned circuit

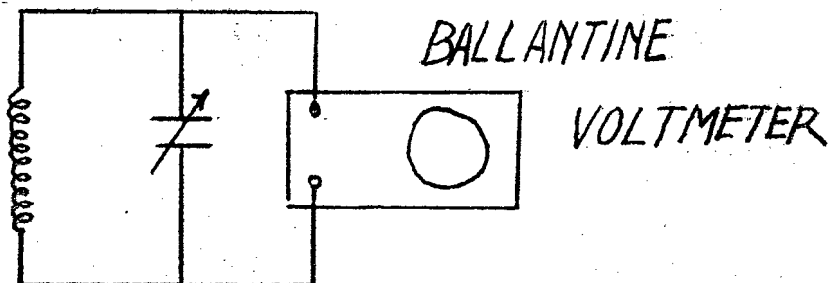and a battery-operated Ballantine voltmeter.

Figure 3. Receiver Circuit.

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Wooden frames supported the transmitter and receiver in position. The transmitter was placed in one trench and the receiver was placed in the other trench so that transmission of the signal from transmitter to receiver was through the 5-foot wall of earth. The plane of each coil was maintained parallel to the trench walls.

Initially, the coils were placed opposite each other. The receiver was kept stationary and the transmitter was than moved in steps of 3 feet along the length of its trench. The voltages induced in the receiver at each of these intervals were recorded. This configuration is essentially equivalent to the transpondor's being buried 5 feet down, with the transmitter coil held above and parallel to the ground.

The induced voltage in the receiver was also measured under conditions where the transmission was through air and the distance separating the two coils was the same as their minimum separation in the trenches.

A reading was taken of the receiver output with the transmitter turned off, to make sure that the voltages measured were not due to unknown sources. This reading over a five minute period was less than 1 millivolt, which is the lowest voltage the Ballantine voltmeter will indicate.

Experimental Data

The measured rms voltages are labeled according to the positions shown in Figure 4.

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RECEIVER COIL

80.5"

5'

POSITIONS OF TRANSMITTER COIL

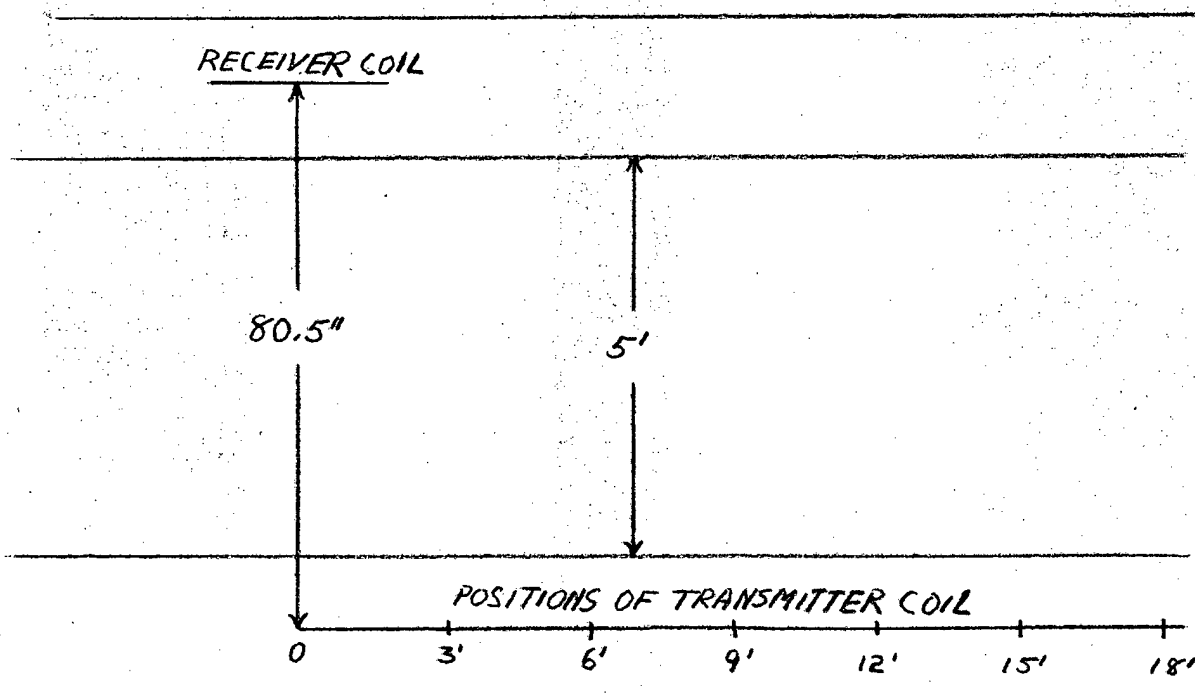0   3'   6'   9'   12'   15'   18'

Figure 4. Positions of Transmitter with
Respect to Receiver

The results of four runs are shown in Table 1.

Table 1

	Run 1	Run 2	Run 3	Run 4
0'	28 V	23 V	21.0 V	22 V
3'	16 V	14 V	7.0 V	12.0 V
6'	1.6 V	1.8 V	1.7 V	2.0
9'	0.03V	0.15V	0.13	0.06V
12'	0.27V	0.21V	0.18	0.22V
15'	0.22V	0.20V	0.21	0.21V
18'	0.15V	0.15V	——	0.12V

The induced voltage in the receiver measured for transmission
through air with a separation of 80.5" between transmitter and receiver
coil was 24.0V.

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Several measurements were made where the transmitter coil was
rotated for maximum signal at the receiver. It was found that, except
for the 0' position, a signal maximum was measured at the receiver for
two particular positions of the transmitter. These positions were found
by rotating counterclock wise and clockwise with respect to the position
of being parallel to the trenches.

Comparison of Experimental Data with Theory.

The induced voltage in one coil due to a second energized coil,
for the case where the two coils are maintained parallel, was calculated
in the Phase I report. The ratio of the induced voltage at some position
Θ (see Figure 5) to the position of minimum distance ($\Theta \approx 0$) is given by

$$\cos^3 \Theta \ (\tfrac{3}{2}\cos^2\Theta - \tfrac{1}{2})$$

RECEIVER

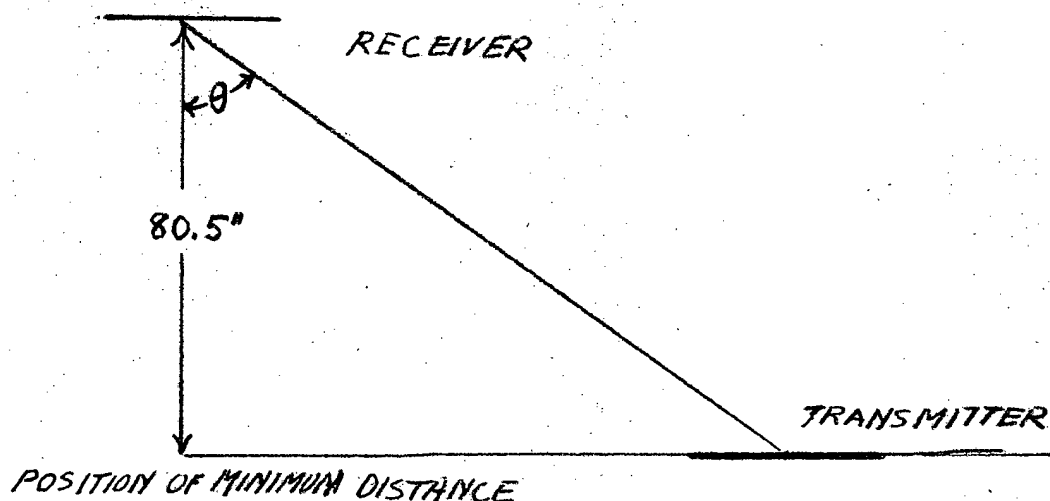θ

80.5"

TRANSMITTER

POSITION OF MINIMUM DISTANCE

Figure 5. Configuration of Transmitter and Receiver
where the transmission path is in air. This expression has been verified
experimentally for transmission in air. Thus, since no attenuation factor
was considered in the derivation, we can conclude that attenuation in air
can be neglected.

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In order to compare experimental results with theory, the expression given above was evaluated for values of θ corresponding to the 3', 6', 9' etc. positions. These results are given in Table II.

Table II

Position	θ	$\cos3\,\theta\ (\frac{3}{2}\cos^2\theta-\frac{1}{2})$
0'	0	1
3'	25.5	0.532
6'	41.8	0.137
9'	53.3	0.00725
12'	60.8	0.0166
15'	65.9	0.017
18'	69.5	0.013

The experimental data was reduced to the same form by dividing the voltages measured at the receiver for the different positions by the voltage at the receiver for the 0' position. In addition, to facilitate comparison these ratios were divided by the corresponding values of the theoretically expected value given in Table II. Table III gives the result of these computations. We have labelled the voltage ratio η i.e. voltage at 0', 3', 6', etc. to voltage at 0' position. The expected value for this ratio as given by the expression of Table II has been called E.

Table III

Position	Run 1	Run 2	Run 3	Run 4	ave η	$\dfrac{\text{ave }\eta}{E}$
3'	0.572	0.608	0.333	0.546	0.512	.962
6'	0.057	0.0783	0.0808	0.110	0.0815	0.595
9'	0.0017	0.00652	0.00618	0.00273	0.00428	0.592
12'	0.00964	0.00913	0.00857	0.010	.00934	0.562
15'	0.00786	0.00870	0.010	0.00955	0.00903	0.531
18'	0.00536	0.00652	———	0.00546	0.00578	0.445

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The values for ave η /E indicate that attenuation exists,

since their magnitude decreases with increase in distance..

If we assume the attenuation is of the form e^{-kr} where k

is the absorption coefficient and r is the distance travelled through

the absorbing medium, then the theoretically expected value should be

of the form

$$\cos^3 \theta \ (\tfrac{3}{2}\cos^2\theta-\tfrac{1}{2}) \frac{e^{-kr}}{e^{-kr_0}} \ .$$

The factor e^{-kr_0} appearing in the denominator is the attenuation

factor for transmissio directly through the 5' wall. It is introduced

to take care of the fact that we have divided by the voltage reading at

the receiver for the 0' position.

The values for ave η /E thus have the expected value as given

by

$$e^{-k \ (r-r_0)}$$

and is equal to unity when $r = r_0$ where $r_0 = 5'$ which is the width of

the wall separating the two trenches. By taking the log of both sides

of the equation:

$$\frac{\text{ave } \eta}{E} = e^{-k(r-r_0)}$$

we get

$$\ln(\frac{\text{ave } \eta}{E}) = k(r-r_0).$$

Using the method of least squares we can evaluate k by

$$\sum_i \ln(\frac{\text{ave } \eta_i}{E_i}) = k \sum_i (r_i-r_0)$$

where the summation is over the experimental values for the various

positions. The distance travelled through the absorbing medium is given

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by $\dfrac{5'}{\cos\Theta}$. The value for k evaluated by this method is 0.113. The
value of $r-r_0$ for the field to fall off to 1/e is 8.85 or $r = 13.9$
feet. The mean deviation for k is $\pm$ 0.086. This gives 0.027 and
0.199 for the probable limits of k which correspond to r equal to 42
feet and 10.02 feet. A value for k was also obtained from the average
value of receiver voltage with transmitter in the 0' position and the
voltage obtained with the same separation of transmitter and receiver
in air. For these data $k = 0.004$ and $r = 250$ feet for an attenuation
of $\dfrac{1}{e}$.

The distance for the field to fall off to $\dfrac{1}{e}$ calculated from
electrical constants[2] for soil is 52 feet for 100 kc. which is within
the range of values obtained experimentally.

The large spread observed in the values for k is probably due
to the difficulty of carrying out careful experiments in the field.
In practical effect, the results range from introducing a 10:1 reduction
in signal on round trip to being negligible, when comparing transmission
through air and soil.

[2] See Report for Phase I p. 33.

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APPENDIX A

Description of Coil
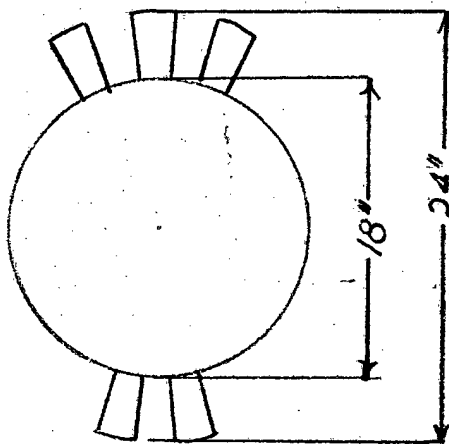
Each coil contained 110 turns of 52 strands of #38 enameled copper wire, wound spider-web fashion on masonite forms. The dimensions of the form are shown in the figure. There were 19 pegs and 19 spaces. The coils had an inductance of 10.3 mh with a distributed capacity of 38.6 mmf. The Q at the operating frequency of 90 kc. was 130.

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